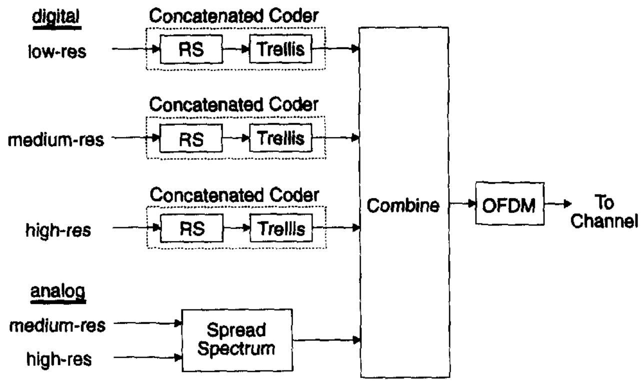

Figure 4: Hybrid Multiresolution Channel Coder.

4.1. Constellation Design

A constellation represents the set of values from which symbols can be chosen for channel modulation. Hybrid symbols convey both analog and digital information. A straightforward method of delivering different classes of digital data uses nonuniform spacing of the digital quantization levels within the constellation. Depending on the quality of the received signal, different amounts of information can be extracted.

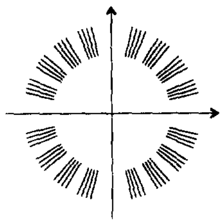

Figure 5: Hybrid Nonuniform 64-PSK Constellation.

We use symbols chosen from a hybrid Phase-Shift-Keyed (PSK) constellation similar to that illustrated in Figure 5. The symbol magnitude represents analog data and is not quantized to levels, but rather is allowed to assume any value in the radial direction. Digital data is encoded in the phase of the symbol. The phase modulation has 64 possible values resulting from 4 *quadrants*, each containing 4 *groups*, each composed of 4 *levels.* The nonuniform spacing between *quadrants*, *groups*, and *levels* conveys three classes of digital data. The low-resolution digital stream is represented by the choice of *quadrant* (4-PSK), which conveys 2 bits per symbol. The medium-resolution digital stream is represented by the choice of *group* within a *quadrant*, a 4-level phase modulation conveying 2 bits/symbol. The high-resolution digital stream is represented by the choice of *level* within a *group*, a 4-level phase modulation conveying an additional 2 bits/symbol. In the present implementation, a phase separation of 18° between *groups* and 3° between *levels* is used.

The lowest resolution service occurs when the channel is sufficiently bad that only the particular *quadrant* is reliably distinguished in the received signal or when a very simple receiver is used. In this case the receiver retrieves two bits/symbol of digital data. As channel conditions improve, better phase resolution allows reliable extraction of more components, yielding more data. Under medium-resolution conditions *groups* are resolved, for a total of 4 bits/symbol, and the first level of analog data is used. Under high-resolution conditions, three levels of digital data (6 bits/symbol) and both analog data streams can be extracted. Due to the nature of analog transmission, the SNR of the analog components improves in a continuous fashion with channel SNR.

4.2. Spread-Spectrum Processing

Spread-spectrum processing combines many parallel data streams into one high-rate data stream with desirable statistical properties. Each data stream is multiplied by a unique Pseudo-Noise (PN) sequence at a much higher rate, spreading the bandwidth accordingly. The resulting parallel product streams are combined to form the spread-spectrum signal. At any instant in time the spread-spectrum signal represents a conglomeration of all the input data streams, each spread over the entire bandwidth associated with the spread-spectrum signal. Thus each data stream is distributed over all the time *and* frequency of the channel. Mutually orthogonal PN sequences allow recovery of each input data stream without crosstalk from the other parallel streams. Due to sequence properties, defects suffered in the channel are distributed among all the components in a controlled manner. Adjusting the relative power of each analog data stream according to its relative importance achieves a bandwidth/SNR tradeoff among parallel streams. Power is proportioned among analog streams to allow the more important data streams to have better SNR, while the less important data streams sacrifice some SNR.

In the context of MR delivery of analog coefficients in an HDTV system, spread-spectrum processing allows three kinds of optimizations. First, it provides for SNR tradeoffs between the medium and high-resolution analog data streams. Second, it exploits shared information between the source and channel coder to allow more important analog data within data streams to have better SNR, while less important data sacrifices some SNR. Lastly, the controlled manner in which channel defects are spread among the components guarantees predictable behavior even in bad channels.

4.3. Forward Error Correction Coding

Forward Error Correction (FEC) coding is applied to the digital data streams to extend the range of the system. Concatenated codes constructed from Reed-Solomon and trellis codes [4] promise the best performance with reasonable complexity using proven technology. Trellis coding combines channel modulation and error correction coding by applying a convolutional coder to the input data stream and representing the redundancy at the output by a bigger constellation rather than an increased symbol rate [6]. The soft-threshold Viterbi algorithm performs trellis decoding, yielding modest coding gains near the desired operating thresholds [5]. Trellis coding can be viewed as a mechanism to regain some of the channel capacity lost to digital quantization within the signal constellation. Reed-Solomon codes, noteworthy for their highly flexible nature and the availability of efficient decoding techniques, correct errors remaining after trellis decoding. In general, concatenated codes are not as powerful as the best comparable single-stage code, but decoding in stages greatly reduces the complexity. The current system uses rate .8 Reed-Solomon codes and rate .5 trellis codes.

4.4. OFDM

Orthogonal Frequency Division Multiplexing (OFDM) is a multi-carrier modulation technique used to deliver a hybrid signal even under harsh channel conditions characteristic of terrestrial broadcasting [3]. The data to be transmitted is distributed over multiple narrow-band carriers that together fill the allowed bandwidth. Frequency overlap of the carriers is allowed, but orthogonality is maintained by shaping the spectrum of the modulated carriers. The modulator and demodulator employ discrete-time Fast Fourier Transform (FFT) techniques, permitting multiplexing without generating multiple analog carriers. A guard interval and gain-correction techniques combat echoes in the channel. Because of the nature of the multiple parallel carriers, the system can actually benefit from multipath interference in certain conditions. The current implementation uses 512 carriers in a 5.5MHz bandwidth.

4.5. Performance

We describe transmission system performance by quality measures of the three data classes under various channel conditions. The digital data streams are described in terms of Bit Error Rate (BER) while the analog data streams are described in terms of the SNR of the recovered data streams. A meaningful way to describe the performance is to plot the BER of the three digital data streams and the SNR of the two analog data streams as a function of the channel SNR as shown in Figure 6. The solid lines falling off to zero from left to right represent the BER curves for the low, medium, and high-resolution components respectively. The dashed lines increasing from left to right show the analog SNR of the medium and high-resolution analog data streams.

We can tune the system parameters to get tradeoffs in the relative performance of the components. For example, by decreasing the low-resolution performance and sacrificing some coverage we can increase performance of the high-resolution data to deliver better pictures further from the transmitter. In Figure 6 this adjustment would be reflected by the low-resolution BER curve moving to the right, while the medium and high-resolution curves (analog and digital) move to the left.

5. RESULTS

In Figure 7 we show pictures reconstructed from a signal received at five different locations within the broadcasting area. The particular picture shown is the fifth frame of a moving sequence. Figure 7a shows the original uncoded

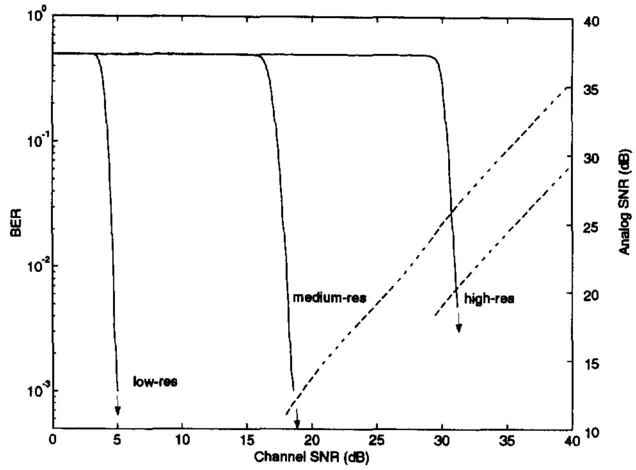

Figure 6: System Performance Curves.

picture. Figures 7b-f demonstrate performance of the system at 6dB, 20dB, 30dB, 32dB, and 40dB channel SNR respectively.

6. CONCLUSION

We describe and demonstrate a system for terrestrial broadcast HDTV that makes good use of channel capacity. Pyramid filtering and hybrid video coding in the source coder extract and compress MR video. A hybrid MR constellation combined with spread-spectrum processing, FEC, and OFDM allow the channel coder to reliably deliver the highest quality video possible to each receiver.

7. REFERENCES

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Figure 7a: Original.

Figure 7b: Low-res at 6 dB.

Figure 7c: Medium-res at 20 dB.

Figure 7d: Medium-res at 30 dB.

Figure 7e: High-res at 32 dB.

Figure 7f: High-res at 48 dB.